FERMILAB MUCOOL TEST AREA CAVITY CONDITIONING CONTROL USING LABVIEW

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Abstract

Automated RF cavity conditioning controls have been implemented in the Fermilab MuCool Test Area using National Instruments LabVIEW. Display of RF parameters, cavity gradient and diagnostic signals are provided for real-time monitoring. Oscilloscope traces and operating parameters are logged automatically. Gradient ramping and cavity breakdown detection allow unattended operation. Key parameters are made available to the Fermilab ACNET system for viewing by users.

SYSTEM OVERVIEW

The MuCool Test Area (MTA) consists of a beamline stub and experimental hall off of the 400 MeV H- section of the Fermilab LINAC [1]. The hall contains power supplies and cryogenics for a 5T superconducting solenoid as well as RF feeds for high power 201 MHz and 805 MHz. Cavity conditioning is currently performed at 805 MHz at up to 13 MW of RF power [2][3][4].

The computer test system consists of a Dell GX620 computer running National Instruments (NI) LabVIEW 2012[5]. Waveforms are acquired with the NI PCI-5105 60 MS/s, 12-Bit, 8-Channel Digitizer/Oscilloscope card. A GPIB bus communicates with the HP E4400B RF Signal Generator, LeCroy 625Zi oscilloscope, and Tektronix DPO7104 oscilloscope.

Triggering of acquisitions is by the RF gate TTL signal from a master timing distribution module. Additional signals into the PCI digitizer card are a diode detected sample of the cavity RF probe signal, a sample of the waveguide reflected power, and an optional signal from a cavity photo detector.

SOFTWARE DESIGN

The MuCool Cavity Test software has evolved over more than six years of activity [6][7]. LabVIEW has been used throughout the process. This latest version has implemented some important new features:

- A simplified user interface with multiple floating front panel windows.
- Cavity waveform analysis during each pulse, including cavity breakdown detection.
- A new cavity tuning algorithm.
- Gradient ramping and breakdown recovery.
- Verbose log files.
- Cavity waveforms are periodically saved to disk and can be viewed later.

- Breakdown events are recorded along with data from preceding and following pulses.
- A few key parameters are available on the ACNET control system.

User Interface

LabVIEW routines are called virtual instruments (VIs). Each VI has a front panel for user interaction and a block diagram that defines the program execution. In the cavity conditioning system the main front panel provides a general view of the cavity signals and pulse status. It also provides a launch point for the cavity conditioning control VIs, such as tuner control and cavity waveform analysis. Figure 1 shows the general flow of the program. Figure 2 shows the layering of various VI front panels. During any given user interaction, the panel of interest can be brought to the foreground or minimized as needed. Additional VIs are available for the user to set the data logging interval and to enter comments into the log file.
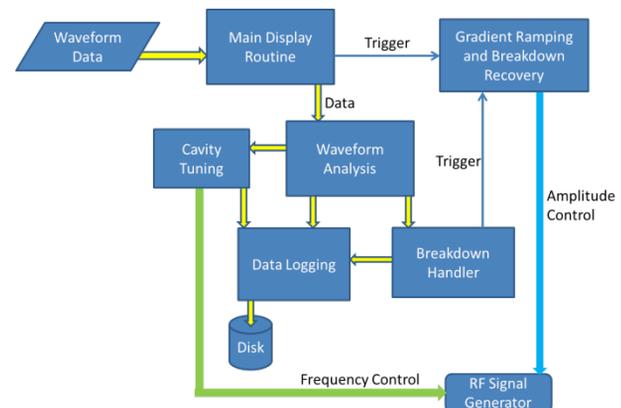

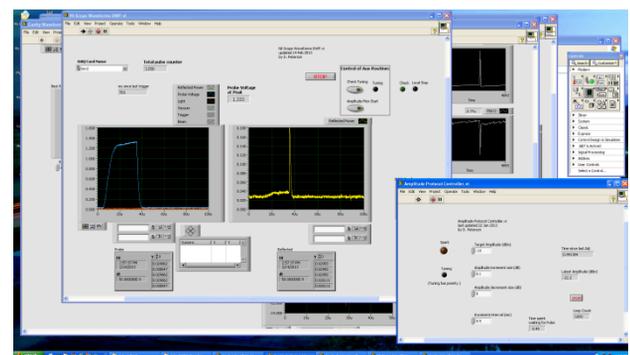Figure 1: Simplified block diagram of the cavity conditioning program.

Figure 2: Screen capture of the overall user interface showing the layering of multiple VI front panels.

Cavity Waveform Analysis

As the waveforms are acquired by the digitizer card they are passed to Cavity Waveform Analysis VI for all of the measurements, breakdown detection and triggering of the breakdown logging routines.

Measurements on the cavity probe waveform include peak voltage, rise time, fall time, exponential fits of filling time constant and decay time constant, and integrated values of cavity and reflected signals both inside and outside the RF gate time. Figure 2 shows the user waveform display of a normal cavity pulse with the RF gate signal and reflected power signal.
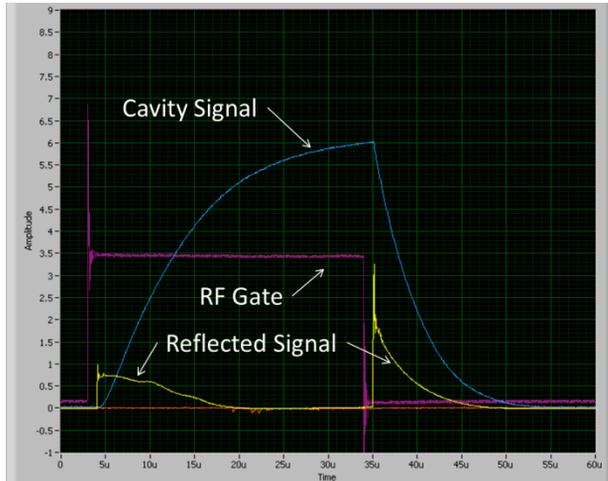

Figure 3: Typical main display showing cavity waveform, RF gate and reflected signal.

Cavity Breakdown Detection

The best way to detect cavity breakdown is to insert a fiber optic cable into the cavity and detect the flash of light when a spark occurs. Figure 4 shows the large light signal during a cavity breakdown event. Unfortunately, not all cavities have been outfitted with optics.
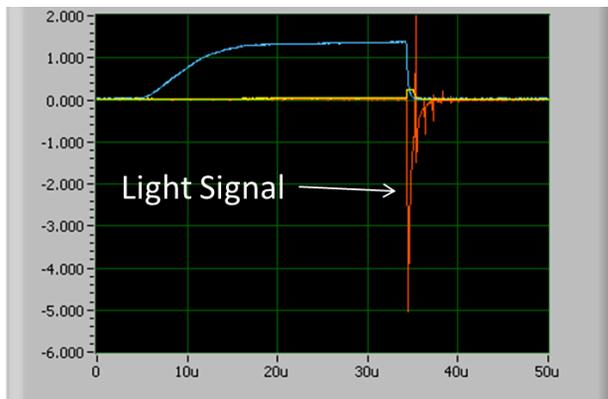

Figure 4: Auxiliary display showing pronounced light signal during a cavity breakdown event.

A reliable alternate method involves measuring the 90% to 10% fall time of the cavity probe waveform and triggering the breakdown capture VIs for any fall time shorter than a user settable trip value. Figure 5 shows a

cavity breakdown event with the extremely steep cavity waveform falling edge. The reflected power spikes momentarily until an external high speed circuit detects the event and turns off the RF drive signal before the end of the RF gate. A typical 90% to 10% fall time in recent tests is approximately 12 µs for normal operation and less than 1 µs during breakdown.
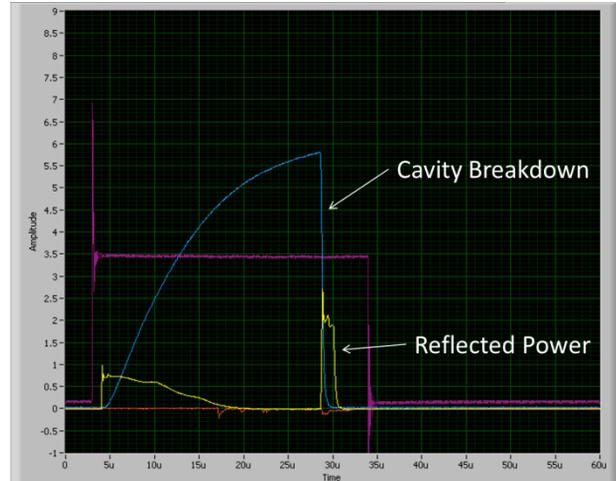

Figure 5: An example of a cavity breakdown event with the accompanying spike in the reflected power.

Cavity Tuning Algorithm

During normal cavity conditioning, enough power is dissipated in the walls of the cavity to raise the temperature and change the resonant frequency. Since the present test cavities do not have any means of compensating for this effect, the RF drive frequency must change to follow the cavity resonance. Previous versions of the software have used a gradient search to determine where the peak resonance occurs. Measurement noise when far off resonance often resulted in the algorithm taking many steps to converge or occasionally failing to converge.

The improved algorithm uses a sequence of n steps to move a predetermined distance, Δf, each side of the present center frequency while also recording either the cavity amplitude response or the ratio of integrated cavity probe signal vs. reflected signal inside the RF gate. The probe/reflected ratio has proven to be a very effective measurement of cavity performance. For efficiency, the step sequence takes the odd numbered steps going down in frequency and even numbers steps going up in frequency. For example, a complete step sequence using 5 steps each side of the center frequency, f_0, would be:

$f_0-\Delta f/n$, $f_0-3\Delta f/n$, $f_0-5\Delta f/n$, $f_0-4\Delta f/n$, $f_0-2\Delta f/n$, f_0, $f_0+2\Delta f/n$, $f_0+4\Delta f/n$, $f_0+5\Delta f/n$, $f_0+3\Delta f/n$, $f_0+\Delta f/n$, f_0.

After the steps are complete the signal vs. frequency array is passed to a Gaussian peak fitting routine which returns the least square fit to the measurements. The algorithm then moves the signal generator frequency by steps of $2\Delta f/n$ to the new calculated center frequency and the tuning cycle is complete. Typical search values in recent cavity testing have been $\Delta f = 10$ kHz and n=10.

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Gradient Ramping and Breakdown Recovery

An important part of cavity conditioning is the ability to push the cavity gradient to high field yet not cause serious damage to the cavity surface. The Amplitude Control routine has user settable parameters for amplitude increment step, step interval, and amplitude decrement if breakdown occurs. Amplitude increment occurs at the step interval except when cavity tuning is active. Amplitude decrement occurs immediately upon detection of a cavity breakdown event. Typical settings are an amplitude increment of 0.04 dB, a step interval of 10 seconds, and an amplitude decrement of 3.0 dB if a breakdown occurs.

Recording to Disk

When the LabVIEW program is started at the beginning of each cavity conditioning "Run", it increments the official run number and creates a file folder with the current date if one is not already present. A text log file is created with the date and run number in the file name. Digitizer waveforms are also stored in a file in the same folder. Due to the possibility of multiple runs in one day or one run spanning multiple days, it was decided to keep the log and waveform file sizes manageable by automatically creating a new folder at 00:00:00 each day of running and opening new files with the appropriate run number.

The log file includes time stamped data such as user comments, manual and automatic amplitude setting changes, periodic captures of cavity waveform parameters, and cavity waveform parameters during breakdown events.

Cavity waveform files are recorded periodically and at each breakdown event. A utility program has been written which provides quick viewing of waveforms in a movie format. The user has the option to single step though capture frames and to send the frame image to a graphic file in .png format or send the waveform data to a comma separated spreadsheet file.

The oscilloscopes trigger on every pulse and can also be commanded to write trace information to their internal hard drives periodically and at each breakdown event.

An additional background utility is constantly recording the digitizer waveform data in a circular buffer of 9 elements. When a breakdown event occurs, the buffer continues for 4 more pulses and then the entire buffer is written to a waveform file. This allows the user to view cavity waveforms surrounding the breakdown event.

Writing to ACNET

A background VI uses XML-RPC to write total cavity pulses, number of breakdown events, RF signal generator frequency and amplitude, cavity peak voltage and other parameters out to the Fermilab ACNET control system at a 1 Hz rate [8]. ACNET parameters are easily viewed on the internet and utilities are in place for automatic notification if values go out of user defined tolerances.

SUMMARY AND PLANS

The continued use of LabVIEW has enabled a rapid and efficient upgrade to the MuCool 805 MHz cavity conditioning controls. New measurement and control routines with automatic recording of cavity performance have permitted long conditioning runs over multiple days and will facilitate testing of other cavity designs [9].

Components are being installed to provide similar cavity conditioning capabilities in the 201 MHz RF systems. In addition to the features implemented in the 805 MHz system, the 201 MHz cavity conditioning system will have active resonance tuning control [10].

ACKNOWLEDGMENTS

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